ON THE NUCLEAR REGION OF M82

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ABSTRACT

The position of the hypothetical Seyfert-like nucleus originally proposed to explain the polarization pattern in M82 is calculated anew in a more quantitative manner. To within the errors involved, the resulting coordinates coincide with those of the infrared nucleus recently observed in this galaxy. The observations are discussed and found to support the Thomson-scattering hypothesis. New observations are suggested that may specify the physical conditions in the nuclear region more completely.

I. INTRODUCTION

Recently several investigators (van den Bergh 1959; Kleinmann and Low 1969a, b) have reported detection of an infrared nucleus in the galaxy M82. Not only could these observations be crucial to our understanding of the so-called "infrared phenomenon in galaxies" in general, but, in particular, they may shed some light upon the type of explosion occurring in M82 and its connection with other "active galaxies," i.e., Seyfert galaxies, quasi-stellar sources, and radio galaxies. Their interpretation is therefore of some importance. The purpose of this Letter is to comment on the relevance of these observations to the blast-wave theory (Solinger 1967, 1969a, b) of the explosion and to point out some consequences thereof.

II. NUCLEAR POSITION

The existence of a Seyfert-like nucleus in M82 was originally proposed (Solinger 1967, 1969a, b) to explain the optical-polarization data (Elvius 1963, 1969; Sandage and Miller 1964). In the proposed model, the near–concentric-circular nature of the orientation of the electric vectors is explained as due to Thomson scattering of light from a Seyfert-like nucleus. The free electrons are produced by a galactic-scale hydrodynamic blast wave, which heats, compresses, and accelerates the circumgalactic medium as it passes through it. A position for the then-hypothetical nucleus was obtained by a trial-and-error method, which consisted of computing the angle ψ_i between radius and electric vector for each point of observation for every trial nuclear position (or explosion center) and then comparing the histograms for different centers. The histogram which peaked most at 90° was taken to correspond to the best choice of nuclear position. The error associated with such a method is not easily estimated with any accuracy.

As a result of the above-mentioned infrared observations, a more refined and quantitative method has been devised to establish the nuclear position from the optical data and to determine the standard deviation associated therewith.

Consider the quantity δ_i associated with the ith group of data:

$$\delta_i = (N_i - \bar{N}) \cos \theta_i + (E_i - \bar{E}) \sin \theta_i , \tag{1}$$

where θ_i is the position angle of the electric vector of the point under observation with coordinates (N_i, E_i) and where $(\bar{N}, \bar{E})$ is the desired nuclear position. The quantity δ_i is simply the distance by which the normal to the electric vector misses the point $(\bar{N}, \bar{E})$. The geometry is illustrated in Figure 1. Thus, when the angle between radius

and electric vectors is 90°, δ_i is zero. Clearly a least-squares fit in the spirit of the previous determination can be found by choosing $(\bar{N}, \bar{E})$ to minimize the function

$$S = \sum_i w_i \delta_i^2 , \tag{2}$$

where i runs over all the data points and the w_i are certain weights. The data have been divided into a set A, consisting of points used in the previous determination, and a set B, which includes 11 more observations outside the body of the galaxy. In computation I, all the w_i were taken as unity, while in computation II, the w_i were proportional to the polarized fluxes detected.[1] The results are listed in Table 1. The errors in the theo-
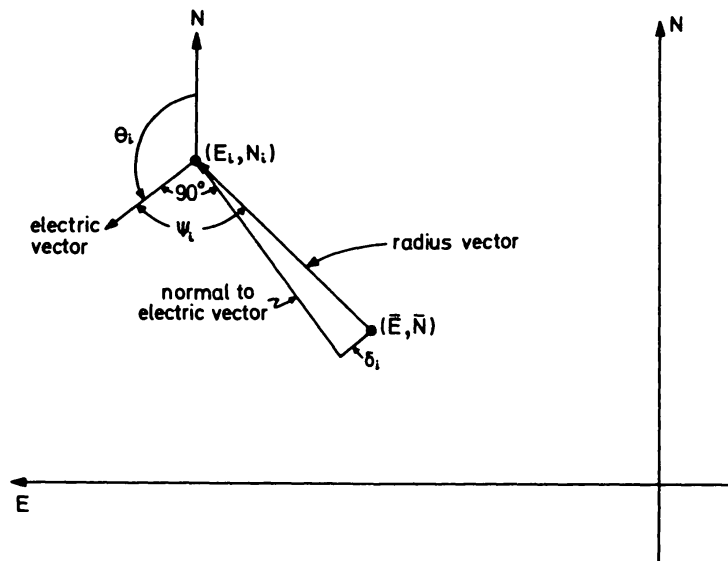

Fig. 1.—Geometry of the determination of nuclear position. The relationship between radius and electric vectors and the associated angles are illustrated for a typical datum. Although the coordinates are left-handed, they were interpreted as right-handed for the computation.

TABLE 1

Nuclear Position in M82

Method	Coordinates*	
	E	N
Theory:		
IA.............	81 ± 4	111 ± 13
IB.............	85 ± 4	112 ± 8
IIA............	79 ± 4	118 ± 12
IIB............	81 ± 3	117 ± 9
Observed†	85 ± 13	118 ± 3

* Seconds of arc relative to BD+70°587.
† Kleinmann and Low (1969*b*).

[1] Because δ_i depends on the distance of the datum from the center as well as on the angle ψ_i, w_i might include a compensating factor, e.g., R_i^{-1}, where $R_i^2 = (E_i - \bar{E})^2 + (N_i - \bar{N})^2$. However, in view of the fact that ψ_i is influenced by light coming from the galactic plane, it is impossible to take all these contingencies into account. The lack of dependence of the results on the weights implies that such a correction is in any case unimportant.

retical quantities given are for a 90 percent confidence interval, i.e., they are 1.645 standard deviations. The agreement with the infrared observations is quite remarkable.

III. NUCLEAR TYPE

a) Observations in the 0.6–1.2µ Range

Van den Bergh (1969) recently proposed that M82 has a "well defined (but nonstellar) nucleus" and concluded that it is a late-type spiral and definitely not a Seyfert galaxy. This result is based on a 48-inch Schmidt plate taken in the near-infrared.

Figure 2 (Plate L1) is an infrared photograph of M82 made with the Lick Observatory 120-inch reflector. It was made by R. Lynds on IN emulsion through an RG 8 filter; thus it is sensitive to a region of the spectrum comparable to the plates of van den Bergh. Van den Bergh's conclusions do not seem to be supported by this observation.

What Lynds's plate seems to show is that there is a rich and complex structure in the near-infrared (which van den Bergh observed) and that the infrared nucleus observed by Kleinmann and Low in the 5–25-µ region is not prominent. This agrees with the general picture of M82 as presenting an edge-on perspective and containing, or being immersed in, a complex of dust. If the amount of dust in the line of sight lying in the M82 plane is comparable to that, say, between the Earth and the galactic center, then, according to Becklin and Neugebauer (1968), one expects on the order of 10^{-5} of the infrared radiated by the nucleus to be directly observable in the range of sensitivity of these plates of Lynds and van den Bergh. It should thus be no surprise that a Seyfert-like nucleus is not observed in this wavelength region, even if it does exist. On the other hand, in the 5–25-µ range the extinction should be much less, and the nucleus should be observable, as Kleinmann and Low have indeed found it to be.

b) Discussion

The above picture can be more fully developed, and some inferences drawn therefrom. Let us suppose that the nucleus is surrounded by clouds of dust in the plane of the galaxy, so that it is obscured at all wavelengths shorter than about 1 µ. What then might one expect to observe? First, if the ratio of scattering to absorption is high for the dust, the size of the region from which infrared is detected should decrease with increasing wavelength up to a certain point at which the scattering becomes negligible. Thus, taking Becklin and Neugebauer's (1968) curve to represent extinction due to scattering, and extrapolating it, we estimate this point to be between 5 and 10 µ.

Recently, variations in the infrared emission of NGC 1068 and NGC 4151 have been reported (Pacholczyk and Weymann 1968). According to the above model, short-term (scale of less than a year) variations may be detectable at long wavelengths ($\lambda > 5 \mu$), if they are occurring, but not at much shorter wavelengths. On the other hand, long-term (scale greater than a year) variations might be detectable at all infrared wavelengths.

Polarization would be expected in the near-infrared if a small diaphragm *not* centered on the nucleus were used. This polarization should be strongly wavelength-dependent in the region $0.6 \mu < \lambda < 5 \mu$, where the scattering is very efficient.

Finally, it should be remarked that the question of excitation conditions in the region of the nucleus is open to observational confirmation. If the proposed Seyfert-like nucleus is at the newly determined position, one might expect the gas in the surrounding region to be radiatively excited. This would manifest itself as a small $H\alpha:H\beta$ ratio, and $H\alpha:[N \text{ II}] \lambda 6583 \gtrsim 3$. Thus a reexamination of the existing spectra and perhaps new observations are called for.

IV. CONCLUSIONS

The observations of Lynds, van den Bergh (1969), and Kleinmann and Low (1969a, b) are not in contradiction with the picture of M82 as a Seyfert-like galaxy. The agreement in
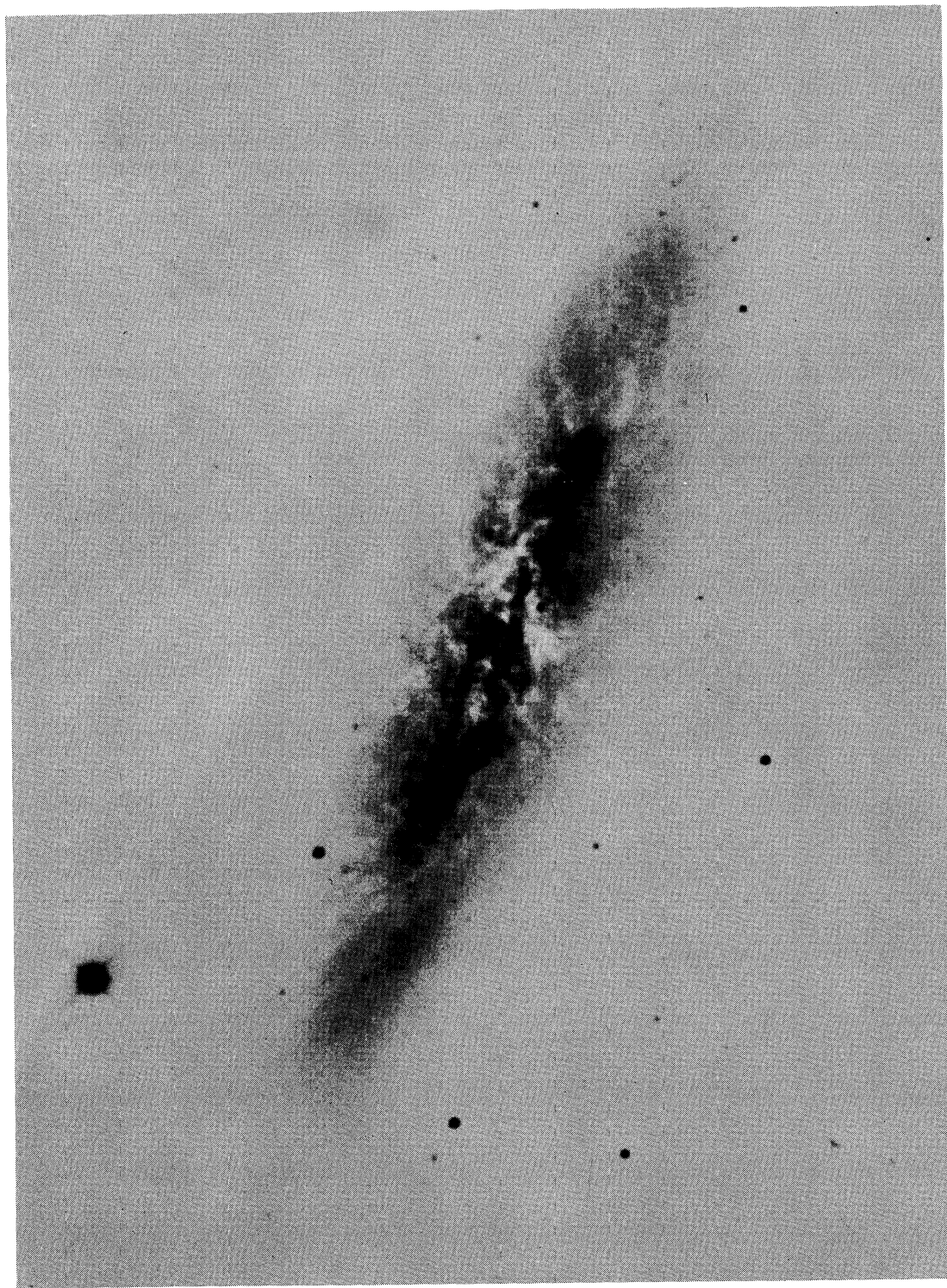
Fig. 2.—Infrared photograph of M82 made by R. Lynds with the Lick Observatory 120-inch reflector. The exposure was 50 min on ammoniated IN emulsion through an RG8 filter.

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position between the infrared nucleus observed by Kleinmann and Low and the inferred Seyfert-like nucleus tends to support this kind of picture. In Table 2 the values of some characteristics of Seyfert galaxies are listed, along with those corresponding to M82. That M82 falls within the ranges of all these characteristics lends further strength to this interpretation.

TABLE 2

COMPARISON OF M82 AND SEYFERT GALAXIES

		NGC						
GALAXY	M82	3516	1068	3227	4051	4151	5548	7469
Spectral type*....	A5	F0	F0	F3	A5	A8	F5	F5
11-cm absolute radio magnitude†....	-20.7	>-21	-21.1	-17.7	-16.6	-19.4	>-22	-22.5
Optical luminosity of nucleus erg sec^{-1}‡....	$10^{43.5\pm0.5}$§	2.5×10^{43}	2×10^{43}	...	10^{42}	1.6×10^{43}	...	5.2×10^{43}

* Humason, Mayall, and Sandage (1956).
† Wade (1968); private communication, preliminary results. The M82 datum is derived from Kellermann and Pauliny-Toth (1968).
‡ Burbidge, Burbidge, and Sandage (1963) (except M82).
§ Predicted by Solinger (1969b).

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